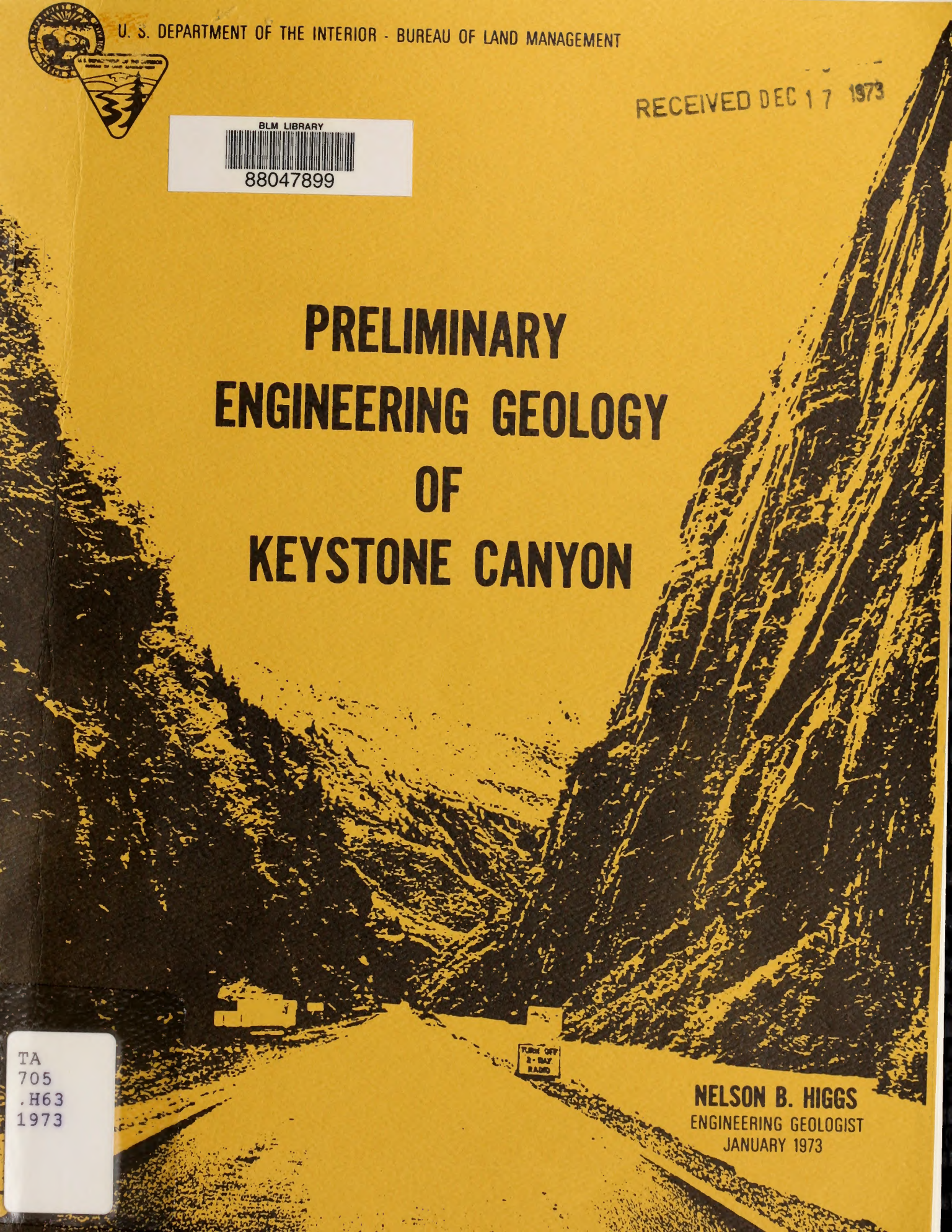
U. S. DEPARTMENT OF THE INTERIOR - BUREAU OF LAND MANAGEMENT

RECEIVED DEC 17 1973

BLM LIBRARY
88047899

# PRELIMINARY ENGINEERING GEOLOGY OF KEYSTONE CANYON




**NELSON B. HIGGS**
ENGINEERING GEOLOGIST
JANUARY 1973

TA
705
.H63
1973

Bureau of Land Management
764 Horizon Drive
Grand Junction, Colorado 81501

## FOREWORD

Keystone Canyon presents a natural transportation corridor between Valdez and the interior. Therefore, this canyon will receive increasing use in the future. The geology of the canyon should be understood so the best routes through the canyon are selected. This paper presents the preliminary engineering geology of the canyon for the purposes of land-use planning.

BLM LIBRARY
RS 150A BLDG. 50
DENVER FEDERAL CENTER
P.O. BOX 25047
DENVER, CO 80225

ID88047899

TA
705
.H63
1973

Bureau of Land Management
764 Horizon Drive
Grand Junction, Colorado 81501

# PRELIMINARY ENGINEERING GEOLOGY OF KEYSTONE CANYON

NELSON B. HIGGS
ENGINEERING GEOLOGIST

JANUARY 1973

BLM LIBRARY
RS 150A BLDG. 50
DENVER FEDERAL CENTER
P.O. BOX 25047
DENVER, CO 80225

U. S. DEPARTMENT OF THE INTERIOR - BUREAU OF LAND MANAGEMENT

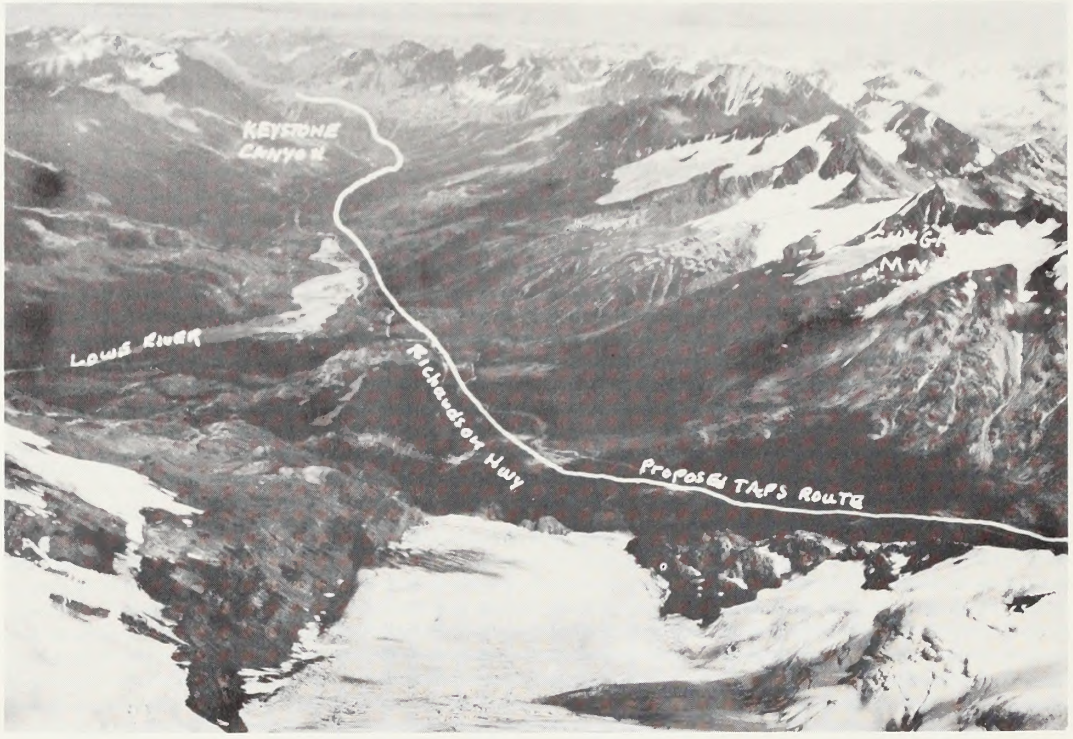
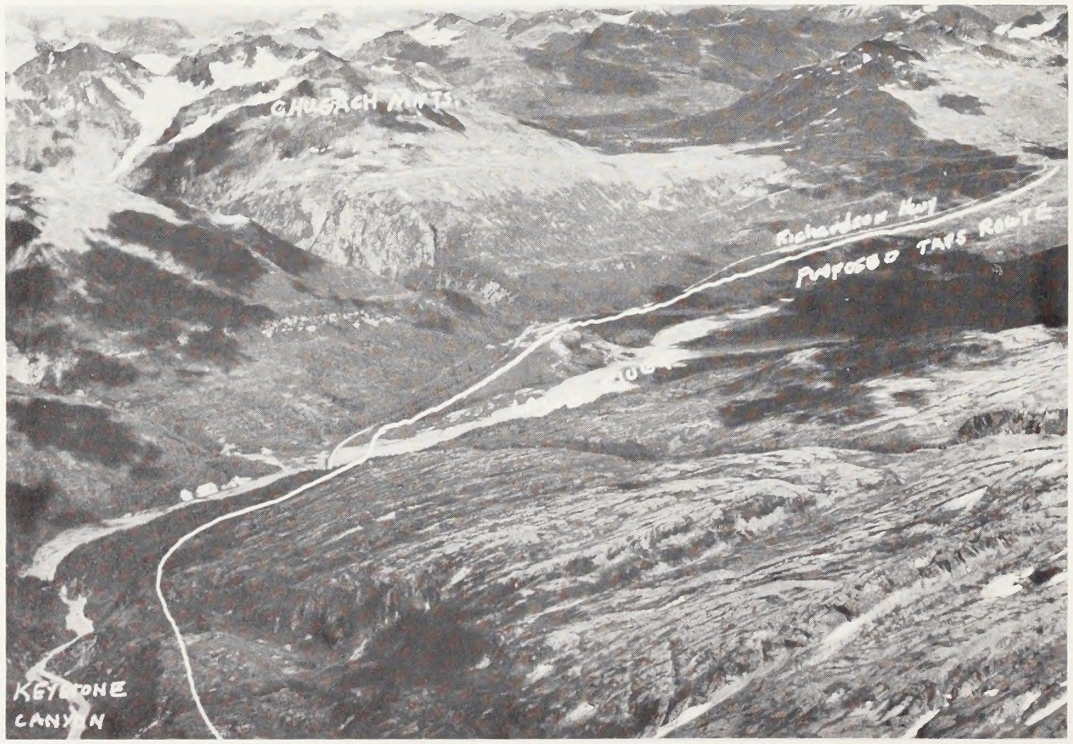



FIGURE 1. Looking roughly southwest toward the north end of

page.2: photo should show the pipeline route diverting from the road into the mountains on the upper righthand portion of the page.

of Keystone Canyon. This view is from a spot over the [illegible] at the left of the words "Keystone Canyon" in Figure No. 1.



CONTENTS


1. Introduction . . . . . 5
2. Rock Competency . . . . . 5
3. Rock Defects . . . . . 5
4. Experience with Valdez Vicinity Rocks . . . . . 7
5. Rock Types at Keystone Canyon . . . . . 8
6. Foliation Trend . . . . . 9
7. Joint Orientation . . . . . 9
8. Joint Spacing . . . . . 11
9. Joint Lengths . . . . . 12
10. Joint Fillings, Healings, and Surfaces . . . . . 12
11. Rock Stability in Existing Tunnels . . . . . 12
12. Terzaghi Classification of Tunnel Rock . . . . . 14
13. Rock Weathering . . . . . 16
14. Seismicity . . . . . 16
15. Highway Slope Instability . . . . . 16
16. Conclusions . . . . . 16

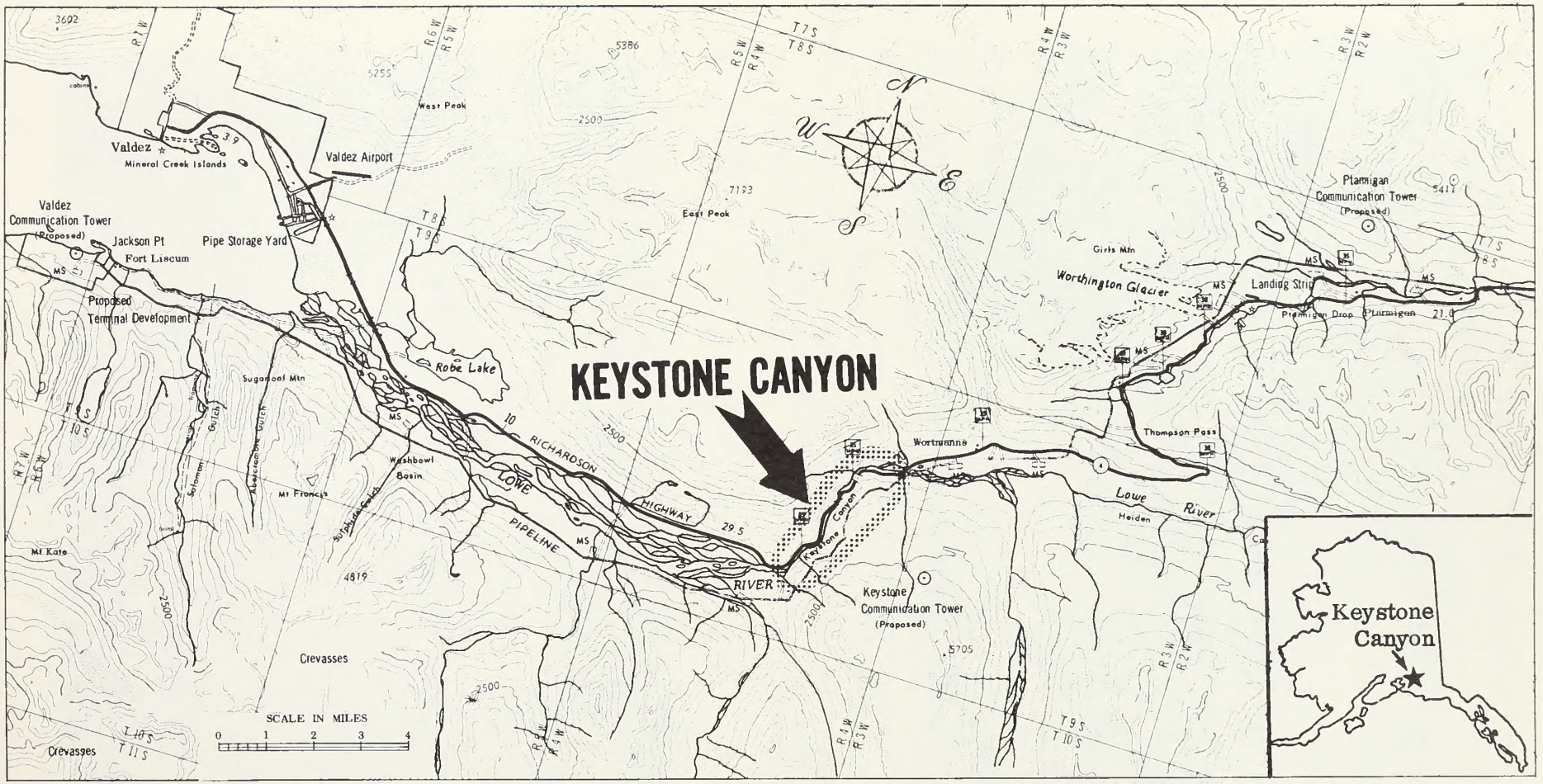



FIGURE 3. Map showing general location of Keystone Canyon in relation to Valdez and Richardson Highway. Proposed trans-Alaska pipeline route as shown is not necessarily indicative of final alignment.

# 1. INTRODUCTION

The proposed 789-mile-long trans-Alaska pipeline will traverse Keystone Canyon about 17 miles north of its terminus at Valdez, Alaska. At Keystone Canyon it is proposed that the pipeline be placed on a high level bench on the east side of the canyon. Figure No. 3 is an atlas map depicting the proposed pipeline routing and giving terrain features.

Keystone Canyon is an approximately 3-mile-long, more than 1,000-foot deep gorge that exhibits unique scenic qualities. It is cut by the Lowe River and has many waterfalls, among which the most notable are Horsetail and Bridal Veil.

Owing to these scenic values and the desire to preserve the natural beauty of Keystone Canyon, alternative routes to the one currently planned along the high bench have been examined. Some of these routes envision tunnels, and some may place the pipeline in zones of less competent rock. Because of these questions of routing, baseline data concerning rock competency and general geologic setting is needed. This paper attempts to fill this gap in the knowledge of Keystone Canyon.

# 2. ROCK COMPETENCY

The term "rock competency" first needs definition and raises the question of just how competent a rock need be for an intended structure. Certainly, the requirements for rock competency are not as great for a small frame dwelling as for a large dam. Even for dams there is a range of rock competency, viz., earth-fill dams do not require the rock competency of concrete gravity dams, and gravity dams in turn do not require the rock competency of arch dams where loads are applied to the abutments.

# 3. ROCK DEFECTS

In analyzing rock competency, it is rock defects rather than the type of rock present that usually affect engineering judgments. If rock fails it usually fails along some plane of weakness. Chief among these planes of

FIGURE 4. Aerial photo of Keystone Canyon.

of weakness are joints, fractures, faults, and, sometimes, foliation planes of metamorphic rocks. These rock discontinuities may serve as avenues of weakness and thus lower the compressive, tensile, and shear strengths of rocks. Also, adversely oriented planes of weakness, such as joints, may

affect slope stability. Thus, an understanding of these rock discontinuity defects is a necessary prerequisite to judging whether a rock will support a structure.

Another important feature that must be ascertained is degree of weathering. When a rock becomes weathered, it loses strength, it is usually of lower unit weight, and it may develop expansive clay minerals that will swell and affect rock integrity. If weathering has progressed sufficiently, the rock can form squeezing ground for tunnel construction. Thus, in a geologic investigation relevant to rock competency, one must determine the extent of rock weathering and the parameters concerning planes of weakness.

With respect to planes of weakness, a joint survey must first be made. This joint survey must determine the attitude of joints, their spacing and length, their openness, degree of healing, type of joint fillings, and roughness of joint surfaces. If the rock is a foliated metamorphic, the orientation, perfection and spacing of the foliation must be determined. Determination of the ease of cleavage along the foliation must also be ascertained.

# 4. EXPERIENCE WITH VALDEZ VICINITY ROCKS

As a result of the 1964 Alaska earthquake, a breakwater for the new town of Valdez was required. Samples of rock from two proposed quarry sources (one from a road cut and the other from a quarry north of Valdez airport) were submitted to the author. Rock from the airport source is a graywacke and from the road cut source, a phyllite. Graywacke is a poorly sorted sandstone, and phyllite is one of the foliated metamorphic rocks intermediate in metamorphic grade between slate and schist.

The graywacke rock submitted shows low rank metamorphism and is suitable for breakwater construction, since it is strong, hard, and durable. In contrast, however, the phyllite is not found suitable for breakwater construction because it splits easily along the contained foliation. This phyllite rock splits along the foliation so readily that instead of processing through a jaw crusher in normal fashion, rock chunks have to be sized by hand sawing. Even with careful sawing it was not always possible to produce the desired dimensioned stone without splitting along the foliation.

Microscopic examination revealed that the phyllite has a well-foliated structure with subparallel layers and lenses of quartz, along with minor feldspar interleaved between layers of parallel-oriented shreds of muscovite mica containing stringers of graphitic carbonaceous material. Muscovite mica is one of the most cleavable of minerals, and the reason why the phyllite split so readily was because of cleavage along the numerous parallel-oriented mica layers within the rock. The mica layers were quite thin, measuring less than 0.1 mm thick, and approximately 12 mica layers occurred within a 0.1 mm traverse. If the phyllite were hit repeatedly with hammer blows, it is probable this rock would eventually cleave to the less than 0.1 mm size layers seen microscopically.

The graywacke has a fine-grained clastic texture, having angular, randomly distributed and haphazardly arranged fragments of fine, sand-sized quartz, feldspar, and rock fragments set in a dense matrix of randomly arranged silt and finer-sized particles of chalcedonic quartz, sericite-muscovite mica, biotite mica, hornblende, and minor interstitial carbonate. The texture is essentially that of a microbreccia, and the toughness of the graywacke is due to the angularity of the included grains and the chaotic and random distribution of its components.

# 5. ROCK TYPES AT KEYSTONE CANYON

Both phyllite and graywacke, similar to that examined from the Valdez vicinity quarries, occur in Keystone Canyon. The rock in Keystone Canyon is best termed a "phyllitic graywacke." In the canyon, the rock grades imperceptibly from graywacke to phyllite. At the center of the canyon the rock is massive graywacke with indistinct foliation; at the north end of the canyon the rock is partially foliated graywacke, and at the south end of the canyon the rock is predominantly phyllite that is easily split along the foliation in hand specimen.

Thus the weakest rock with respect to cleavage along the foliation occurs at the south end of the canyon. Zones of highly phyllitic rock (A), zones of least phyllitic rock (B), and zones of intermediate phyllitic rock (C) are shown in Figure No. 5.

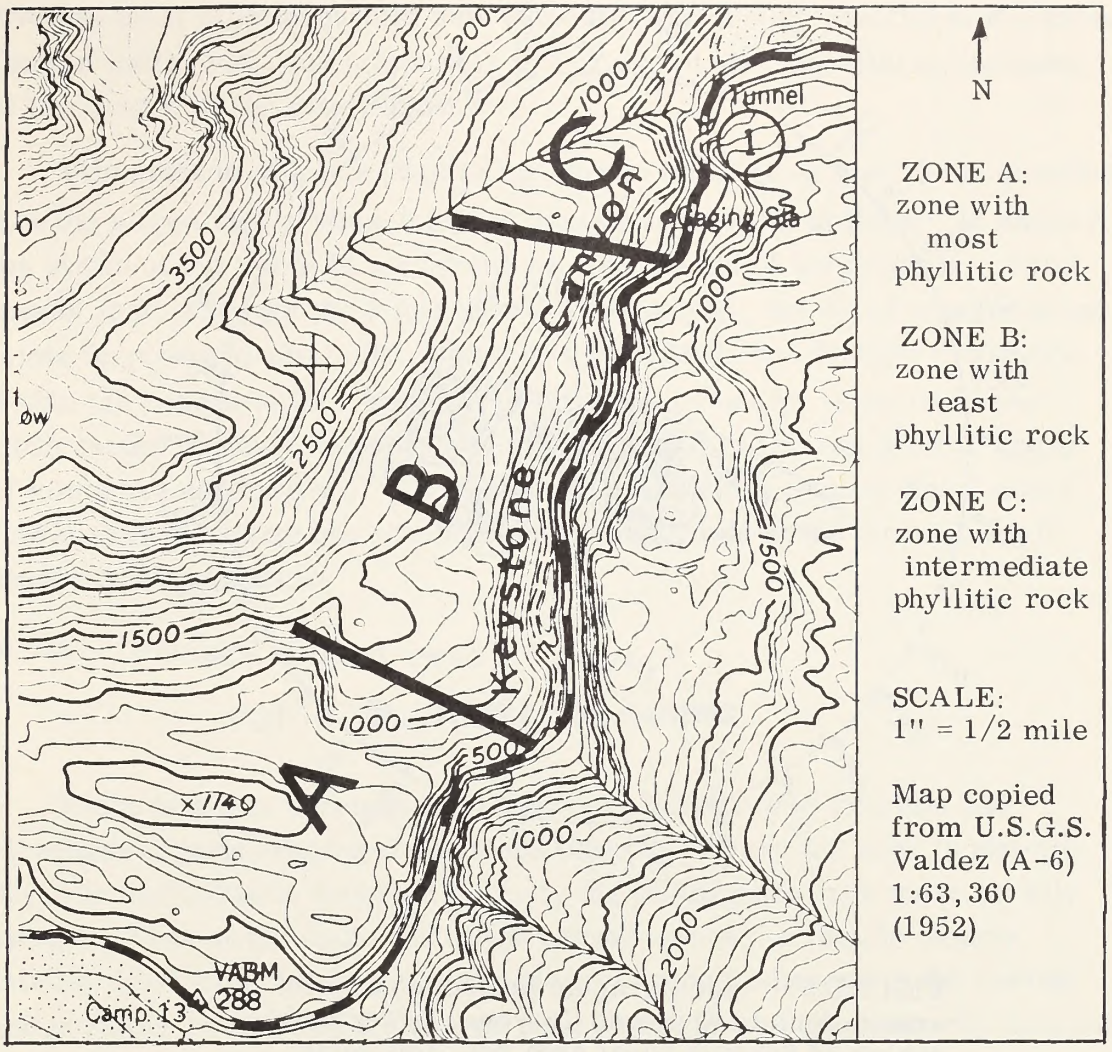



FIGURE 5. Phyllitic rock zones in Keystone Canyon

# 6. FOLIATION TREND

The foliation is at constant trend throughout the canyon and cuts across or trends across the canyon at an average strike of about N80-85E. The foliation dips to the north at angles between 55° and 65°.

# 7. JOINT ORIENTATION

There are three sets of joints in Keystone Canyon. On set, the major

page 9: On set should read One set.

econd most important set

et, a minor set, strikes

N30-45E and dips 60-80° southeast. The results of the joint analyses are displayed in stereographic projection in Figure No. 6.

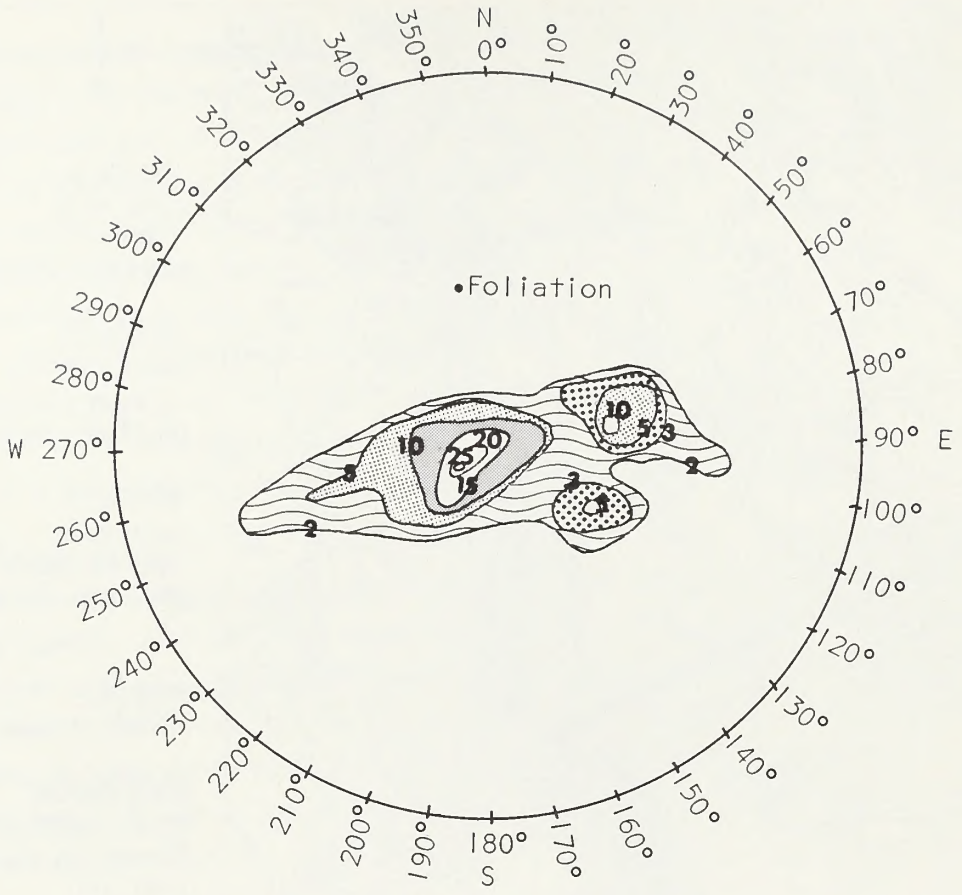



FIGURE 6. Stereographic projection of joint orientations in Keystone Canyon. Lower hemisphere of Schmidt equal area net, 400 joints plotted.

The joints were plotted on the lower hemisphere of a Schmidt equal area net and contoured by the hexagonal Kalsbeck counting net contained in Structural Geology - An Introduction to Geometrical Techniques, by Donald M. Ragan. Four hundred joints were hand-plotted. The stereographic projection also contains a plot of the foliation.

Analyses show that the major joint sets are at about right angles to the foliation. This finding of joints at about right angles to the foliation is in line with the findings of Terzaghi (1946), who states (p. 27): "Metamorphic rocks commonly contain two or more sets of joints oriented approximately at right angles to the direction of cleavage." (Cleavage means foliation.)

The two most prominent joint sets (N5-15W) are closely parallel to Keystone Canyon walls, viz., the joints "run up" or are closely parallel to the trend of the canyon walls (See Figure 9).

This attitude of joints paralleling canyon walls gives rise to the question: Are the slopes stable since the joint system is parallel to them? In answer, the strike of the joints is not fortuitous, but the dip of the joints is. This means that, although the joints parallel the canyon, the dip of most of these joints is generally about 70°, and thus the joints do not daylight downslope within the canyon walls. Because of this fortuitous dip, there has been little record of slope instability within the canyon. The two N5-15W sets of joints are apparently a regional tectonic fabric, as Coulter and Coulter (1961) show the same preferred orientation of joints in the adjacent north Valdez A-5 quadrangle.

page 11: "about" should read, "above."

## 8. JOINT SPACING

There is a direct relationship between the degree of foliation and closeness of joint spacing at Keystone Canyon. Where the rock is strongly phyllitic and foliation becomes perfect, the jointing becomes more closely spaced. Thus at the south end of the canyon where the rock is closely foliated (phyllitic), joints are more closely spaced; whereas in the central and northern portions of the canyon where rock is less pronouncedly foliated, joints are generally widely spaced. Tabulated below are the percentage of closely, moderately, and widely spaced joints obtained from outcrops at the north, middle, and southern sectors of the canyon:

SPACING PERCENT*

| Location | Close | Moderate | Wide |
|---|---|---|---|
| North End Canyon, north of highway tunnel | 5 | 15 | 80 |
| North End Canyon, south of highway tunnel | 6 | 29 | 65 |
| Center Canyon | | | 100 |
| South End Canyon | 46 | 26 | 28 |

*Closely spaced is less than 0.3 feet apart, moderately spaced is 0.3 to 0.9 feet apart, and widely spaced is greater than 0.9 feet apart.

How is joint spacing relevant to slope stability? Simply stated, if there are more joints that are closely spaced, there are more joints available for potential failure. Accordingly, the south end of the canyon has a more adverse joint spacing configuration than the north and central portions of the canyon.

## 9. JOINT LENGTHS

Joint lengths could only be measured at the central portion of the canyon. Here, at the central portion, a joint was traced along its length for about 275 feet. Thus, at the central portions of the canyon, joints are not only widely spaced but traceable along the strike for considerable distance. Joints at the south end of the canyon are short in length.

## 10. JOINT FILLINGS, HEALINGS, AND SURFACES

If a joint is healed by some hard secondary mineral matter, it is usually stronger than when unhealed. Exceptions to this rule are if the joint is healed with a clay mineral or some other soft mineral that has low strength. Montmorillonite clays are particularly bad along joints because of their expansive properties.

In Keystone Canyon most of the joints are open and unhealed. A few joints having hard secondary quartz are the only joint healings recognized. If a joint has rough surfaces along points of joint contact, there is less chance of failure than if the joint is strictly planar. (Essentially the coefficient of friction would be greater.) Most of the joints in Keystone Canyon have straight or linear surfaces and generally relatively smooth surfaces.

## 11. ROCK STABILITY IN EXISTING TUNNELS

There are two short tunnels in existence at the north end of Keystone Canyon. These are the highway tunnel at the very north end of the canyon and an old railroad tunnel a short distance south of the highway tunnel.

FIGURE 5. Mouth of railroad tunnel in north end of Keystone Canyon.

The railroad tunnel was built around 1905, but has been abandoned since then. This tunnel trends about N 20 E and is about 230 feet long. It is horseshoe-shaped and narrows in dimension as one proceeds from the south portal to the north portal. The railroad tunnel is unlined and contains no supports. A small quantity of rock has fallen near the center of the

tunnel where joints became closely spaced (less than 6 inches apart); otherwise the tunnel is virtually intact with no signs of rock failure. Except for the zone noted, tectonic joints are generally widely spaced, near vertical, and trend N 15 W, or at about 20° from the trend of the railroad tunnel. The rock is imperfectly foliated, and the foliation trends about N 75 E, dips 50° N, and is essentially at right angles to the tunnel.

Because of traffic hazards, the highway tunnel was not examined in detail. The horseshoe-shaped highway tunnel is unlined and, except at the north and south portals where timber supports are present, unsupported. The unlined sections are taking water. At the north portal, portions of timber sets had to be replaced or shimmed; however, it is not known whether this remedial action was prompted by rock failure or faulty construction. The State Highway Department has performed studies for both lengthening and lining the tunnel. At the south end of the tunnel a large talus body occurs, and large blocks of rock have fallen from this talus body into the highway, blocking traffic.

The data gleaned from examination of these tunnels suggests that tunnels oriented at near right angles to the foliation and in zones of widely spaced joints and in poorly foliated graywacke can be unsupported, except at portals. The tunnels should be lined because of water intake. If joints are closely spaced within this rock, rock bolting or light supports may be necessary.

# 12. TERZAGHI CLASSIFICATION OF TUNNEL ROCK

Terzaghi's classification for tunnel rock is shown in Figure No. 8. It gives rock load equations based upon the rock conditions and breadth and/or height of the tunnel. It will be noted that there is considerable range in the values that can be used in the equations; for example, one must choose within the range from 0 to 0.5 B for hard stratified or schistose rock. Since it may be desirable to tunnel through Keystone Canyon to avoid environmental conflicts, the author has grouped the rocks within the canyon based upon surficial exposures within Terzaghi classification.

Referring to Figures No. 5 and 8, Zone A rocks at the south end of the canyon, which are highly schistose and closely jointed, are placed in either the moderately blocky and seamy or very blocky and seamy categories. Rock within Zone B which is faintly foliated graywacke with widely spaced joints is placed

Rock load $H_t$ in feet of rock on roof of support in tunnel with width B (ft) and height $H_t$ (ft) at depth of more than $1.5(B+H_t)$. [1]

| Rock Condition | Rock Load $H_t$ in feet | Remarks |
|---|---|---|
| 1. Hard and intact | zero | Light lining, required only if spalling or popping occurs. |
| 2. Hard stratified or schistose[2] | 0 to 0.5 B | Light support. See Fig. 38. |
| 3. Massive, moderately jointed | 0 to 0.25 B | Load may change erratically from point to point. |
| 4. Moderately blocky and seamy | 0.25 B to 0.35 $(B+H_t)$ | No side pressure. See Fig. 39. |
| 5. Very blocky and seamy | (0.35 to 1.10) $(B+H_t)$ | Little or no side pressure. See Fig. 40. |
| 6. Completely crushed but chemically intact | 1.10 $(B+H_t)$ | Considerable side pressure. Softening effect of seepage towards bottom of tunnel requires either continuous support for lower ends of ribs (Fig. 41) or circular ribs (Fig. 42). |
| 7. Squeezing rock, moderate depth | (1.10 to 2.10) $(B+H_t)$ | Heavy side pressure, invert struts required. Circular ribs are recommended. |
| 8. Squeezing rock, great depth | (2.10 to 4.50) $(B+H_t)$ | |
| 9. Swelling rock | Up to 250 ft. irrespective of value of $(B+H_t)$ | Circular ribs required. In extreme cases use yielding support. |

1. The roof of the tunnel is assumed to be located below the water table. If it is located permanently above the water table, the values given for types 4 to 6 can be reduced by fifty per cent.
2. Some of the most common rock formations contain layers of shale. In an unweathered state, real shales are no worse than other stratified rocks. However, the term shale is often applied to firmly compacted clay sediments which have not yet acquired the properties of rock. Such so-called shale may behave in the tunnel like squeezing or even swelling rock.

   If a rock formation consists of a sequence of horizontal layers of sandstone or limestone and of immature shale, the excavation of the tunnel is commonly associated with a gradual compression of the rock on both sides of the tunnel, involving a downward movement of the roof. Furthermore, the relatively low resistance against slippage at the boundaries of the so-called shale and rock is likely to reduce very considerably the capacity of the rock located above the roof to bridge. Hence, in such rock formations, the roof pressure may be as heavy as in a very blocky and seamy rock.

FIGURE 8. Terzaghi-Classification of Tunnel Rock

in either hard stratified, schistose, or massively jointed categories. Rock in Zone C, which is intermediate between Zones A and B types, is placed in the hard stratified or schistose category. These rock classifications are based upon the weakest rock types in each section, pointing out that the rock at the south end of the canyon is the poorest quality.

# 13. ROCK WEATHERING

No intervals of severely weathered rock were observed within the canyon. The rock generally has a fresh and unweathered appearance. Minor iron oxide staining along joints was the only weathering feature noted.

# 14. SEISMICITY

The 1964 Alaska earthquake, having a Richter magnitude of 8.5, nearly destroyed the nearby town of Valdez. Since Keystone Canyon has a major set of joints trending up the canyon and parallel to rock slopes, it would be expected that if slope failures were going to occur in the canyon, they would have occurred during an earthquake of this magnitude. No evidence of rock failures in Keystone Canyon was recorded as the result of this earthquake.

# 15. HIGHWAY SLOPE INSTABILITY

Geologists of Valdez District of Alaska Department of Highways were contacted and asked if there were any instances of slope instability within Keystone Canyon along the highway. Except for the rockslide in talus debris by the highway tunnel, they could point to no other instances of slope failures within the canyon.

# 16. CONCLUSIONS

a. Rock cuts on proposed trans-Alaska pipeline route should be oriented so as to be along the major joint system which strikes N 5-15° W.

b. Concern about rock instability (if there is any at all) should center at the southern end of the canyon where the rock is subject to cleavage, because it is strongly phyllitic, and joints are more closely spaced.

c. The foliation strikes across the canyon at a constant trend, and the major joint system is oriented at near right angles to the foliation or up the

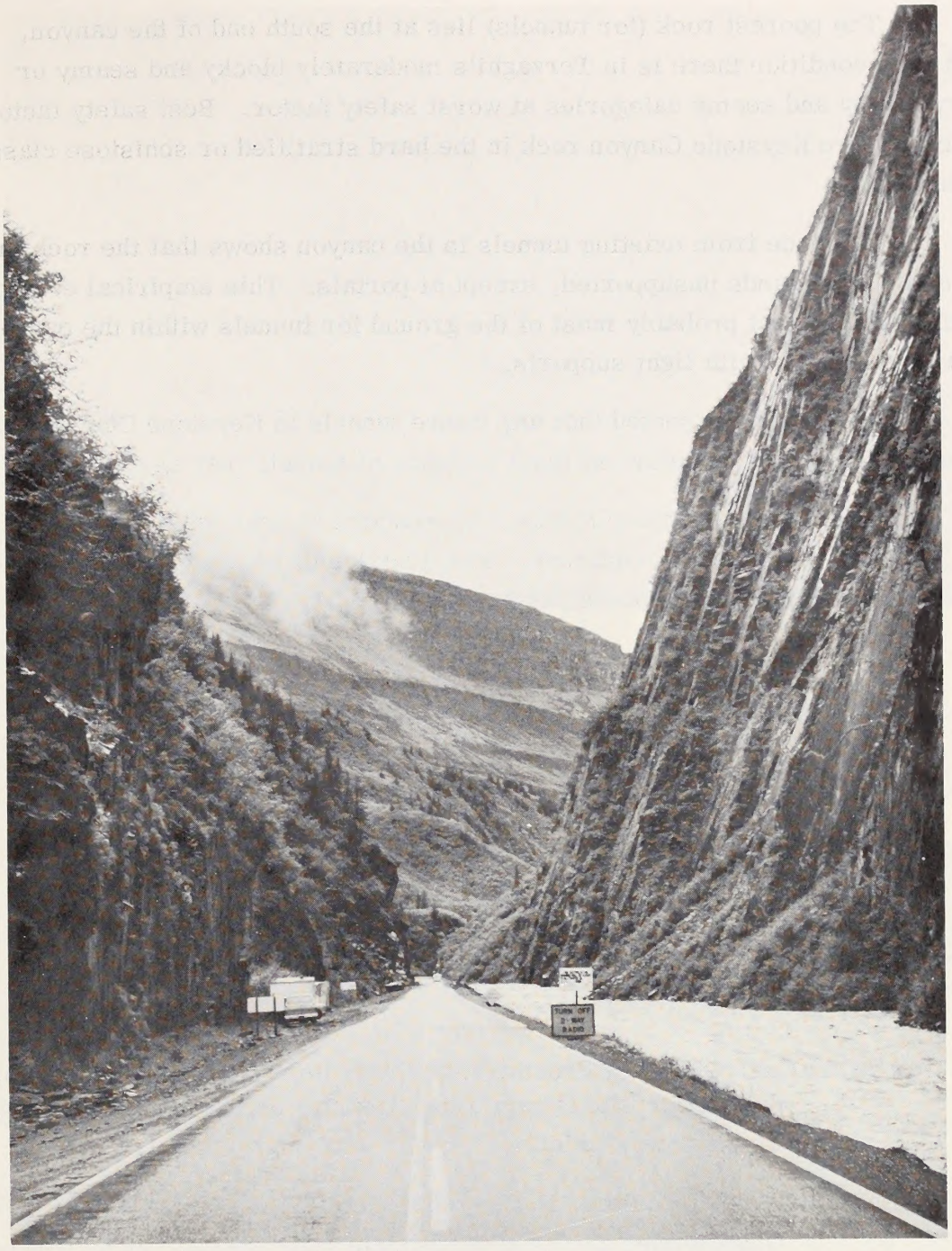


FIGURE 9. Looking up Keystone Canyon from the highway, with the Lowe River at right. Note how joint system at right follows canyon.

canyon, and thus parallel to slopes. This configuration of joint foliation orientation in metamorphic rocks is in line with the findings of Terzaghi.

d. Although the joints parallel canyon slopes, they do not daylight at the toe of slopes, and this is probably the main reason there has been no recorded slope failures in Keystone Canyon, even with an 8.5 magnitude earthquake.

e. The poorest rock (for tunnels) lies at the south end of the canyon, and rock condition there is in Terzaghi's moderately blocky and seamy or very blocky and seamy categories at worst safety factor. Best safety factor places entire Keystone Canyon rock in the hard stratified or schistose classification.

f. Evidence from existing tunnels in the canyon shows that the rock in these tunnels stands unsupported, except at portals. This empirical evidence would indicate that probably most of the ground for tunnels within the canyon can be supported with light supports.

g. It should be expected that any future tunnels in Keystone Canyon will take on water, and therefore at least portions of tunnels may need lining.

h. Possible future tunnels should be oriented at near right angles to the foliation to minimize overbreak. The question of whether tunnels should follow the joint system requires further study.

BLM LIBRARY
RS 150A BLDG. 50
DENVER FEDERAL CENTER
P.O. BOX 25047
DENVER, CO 80225

## REFERENCES CITED

Terzaghi, Karl, 1946, in Proctor and White, Rock Tunneling with Steel Supports. The Commercial Shearing and Stamping Company. Youngstown, Ohio.

Coulter, H.W. and Coulter, E.B., 1961, Geology of the Valdez (A-5) Quadrangle, Geologic quadrangle map GS-142. U.S. Geological Survey.

R'S CARD
73
B.
gineering
eystone Canyon

DATE RETURNED
OFFICE
(Continued on reverse)

TA 705 .H63 1973
Higgs, Nelson B.
Preliminary engineering
geology of Keystone Canyon

BLM LIBRARY
RS 150A BLDG. 50
DENVER FEDERAL CENTER
P.O. BOX 25047
DENVER, CO 80225